Femtoscopy with multi-strange baryons at RHIC

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Abstract

An update on femtoscopic π–Ξ correlations in Au+Au collisions as measured by the STAR experiment at RHIC is presented. Centrality dependence of Gaussian radii and relative emission asymmetry was extracted for the first time.

1 Introduction

The matter created in collisions of heavy ions exhibits properties suggesting that a state with deconfined partonic degrees of freedom was reached [1]. Current data on spectra and elliptic flow from Au+Au collisions at RHIC energies demonstrate that hot and dense system created in the collision builds up substantial collectivity leading to rapid transverse expansion.

A study of production of multi-strange baryons is of high importance since the collective behavior of these particles, manifested by large values of observed elliptic flow together with its observed constituent quark scaling, suggests that collective motion was already achieved prior to hadronization-already at the partonic level. The space-time structure of the particle emitting source is strongly affected by a collective expansion. It shows up as an effective decrease of measured HBT radii and a difference between average emission points for particle species with non-equal masses. The non-identical particle correlations can be hence used as an independent cross-check of flow of multi-strange baryons in heavy-ion collisions by measuring the flow-induced emission asymmetry.

Hydrodynamics-based models [2] predict a mass-ordering of average space-time emission points with the effect increasing with a mass difference of the measured particle pair. Since this effect is predicted to increase with a mass difference between the particles, studying correlations in system, such as $\pi-\Xi$, where the mass difference is large, should provide important test of transverse expansion of the matter and flow of multi-strange baryons.

2 Data selection and analysis technique

The result presented in this paper expand our previous analysis in [3]. In this analysis data set of Au+Au collisions at energy $\sqrt{s_{NN}}$=200 GeV recorded by the STAR experiment during a Run IV(2004) has been used. The available statistics dictates the use of only three centrality bins corresponding to a fraction of total hadronic cross section of 0-10%, 10-40%, and 40-80%.

STAR detector is capable to detect charged hadrons at mid-rapidity $|y| < 0.8$ at full azimuthal angle and identify primary pions via energy loss (dE/dx) in the STAR main TPC. This method limits the pion transverse momenta to $0.08 < p_t < 0.6$ GeV/c. Primary Ξ ($\bar{\Xi}$)-hyperons are topologically reconstructed via their dominant decay chain $\Xi \to \Lambda + \pi$, $\Lambda \to \pi + p$. The particle identification method together with acceptance of the STAR detector allows to reconstruct Ξs at mid-rapidity in the range of $0.7 < p_t < 3.0$ GeV/c.

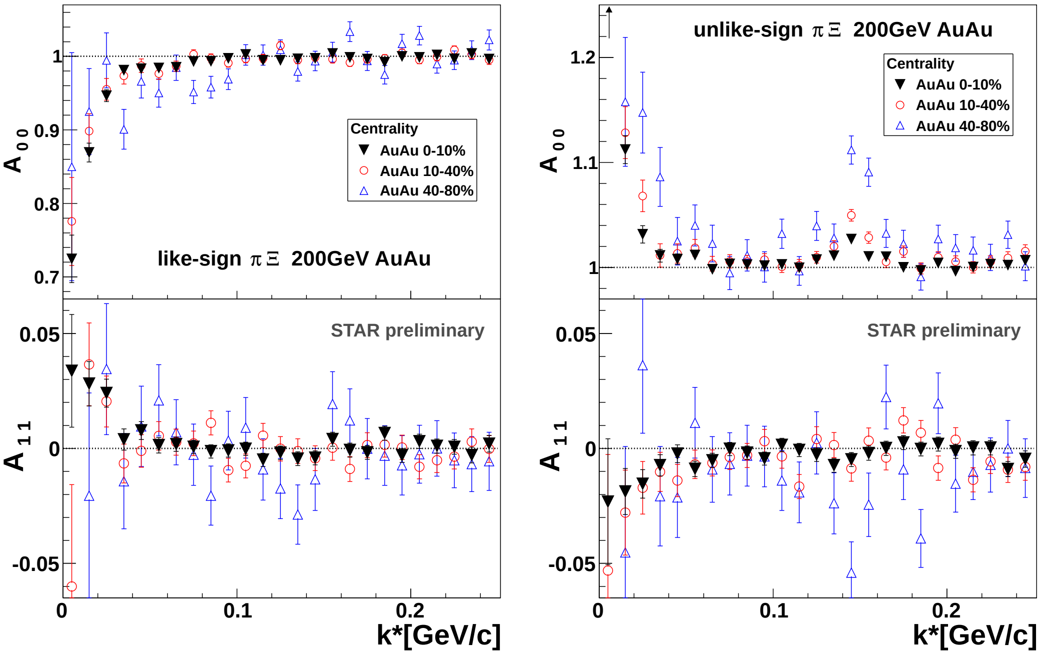
The correlation function, obtained by event-mixing method, was corrected for purity of $\pi-\Xi$ pairs calculated as a product of purities of both particle species. While Ξ-purity was obtained from reconstructed Ξ invariant mass plot as a function of transverse momentum, the purity of pion sample was estimated from $\sqrt{\lambda}$ of the standard parametrization of the identical $\pi-\pi$ correlation function[4, 6]. The purity correction is performed individually for each $\vec{k^*} = (k^*, \cos\theta, \varphi)$ bin of the 3-dimensional correlation function $C(\vec{k^*})$.

3 Correlation functions

The 3-D correlation function $C(\vec{k^*})$ contains both, the information about the size of the source and the information about relative emission asymmetry. To access this information a decomposition of $C(\vec{k^*})$ into the spherical harmonics is used [7]. The coefficient $A_{0,0}(k^*)$ then represents the angle-averaged $C(k^*)$ and coefficient $A_{1,1}(k^*)$ is sensitive to the emission asymmetry [8].

In Figure 1(a) and 1(b) is presented a centrality dependence of $A_{0,0}(k^*)$ and $A_{1,1}(k^*)$ for a combined like and unlike-sign $\pi-\Xi$ correlation function in $\sqrt{s_{NN}}$=200 GeV Au+Au collisions. Both the low-k^* Coulomb-dominated region and region at $k^* \sim$ 158MeV/c, dominated by $\Xi^*(1530)$ resonance exhibit strong centrality dependence in both coefficients. The source size as well as the relative emission asymmetry grow with centrality of the collision.

A comparison of the most central data with theoretical predictions is shown in Figure 2 for three different parametrizations of the source. In these calculations the momenta of the particles are extracted from the real data and



(a) (b)

Figure 1: Centrality dependence of $A_{0,0}(k^*)$ and $A_{1,1}(k^*)$ coefficients of spherical decomposition of the $C(k^*)$ from Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV for combined (a) $\pi^+ - \Xi^+$ and $\pi^- - \Xi^-$ (b) $\pi^+ - \Xi^-$ and $\pi^+ - \Xi^-$ pairs.

their emission coordinates are calculated using given model. The strength the correlation due to the final state interaction(FSI) is obtained using an approach of Pratt and Petriconi [9].

First calculation uses Gaussian parametrization of the source for both particle species. For pions the Gaussian radii are taken from $\pi - \pi$ analysis in [6]. The Ξ source is then assumed to be significantly smaller(R = 2fm) and shifted by 8fm towards the edge of the source in order to introduce "by hand" the effects of the transverse expansion. While the theoretical correlation function describes the behavior of the data in the Coulomb region it gives opposite sign of the A_{11} coefficient in the Ξ^* region. Since the Gaussian parametrization contains no flow-induced correlation between particles momenta and emission coordinates it may not be valid for description of the source at higher k^*.

To incorporate more realistic description of the emission from transversely expanding source we utilize hydro-inspired models: the Blastwave Model [2] and HYDJET++ [5]. The later one also includes effects of resonances and their decays. Both of these models, as shown in Figure 2, describe

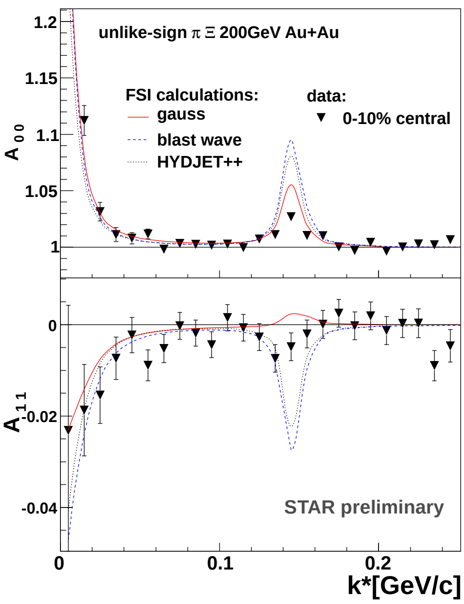


Figure 2: Comparison of 10% most central data from Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV for unlike-sign $\pi-\Xi$ pairs with theoretical FSI calculations using emission coordinates from Gaussian (solid) blast wave (dashed), and HYDJET++ (dotted) model.

qualitatively not only the low k^* Coulomb part of the correlation function, but also give the right sing of A_{11} coefficient in the region of Ξ^*. It is notable that the calculations in the Coulomb part are at or slightly bellow the data, but in the Ξ^* region the calculations strongly overshoot the data in both A_{00} and A_{11} coefficients. Despite this inability to fully calculate strength of the Coulomb and strong part of the $C(\vec{k^*})$ at the same time it demonstrates that the flow-induced correlation between particles momenta and emission coordinates are necessary for qualitative description of the measured data.

4 Coulomb fitting

Since the Coulomb and strong region of the correlation function cannot be described at the same time we extract the information about the size and asymmetry by fitting only the low-k^* Coulomb region, excluding the region of Ξ^* resonance. The source is parametrized by Gaussian shape with a single

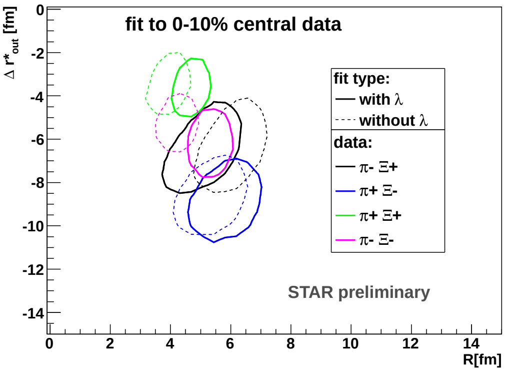


Figure 3: Results of the fit to the most central 0-10% data. 1-σ contours in the (R-Δr^*) plane from fits without(dashed) and with(solid) λ.

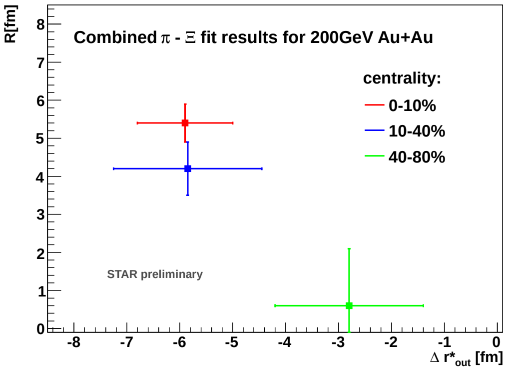


Figure 4: Centrality dependence of the fit to the Coulomb part of the $\pi-\Xi$ correlation function from Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV.

radius R and a relative shift in the *out* direction Δr^*:

$$S_{PS}(r^*, k^*) \sim \exp\left[-\left(\left(r^*_{out} - \Delta r^*_{out}\right)^2 + r^{*2}_{side} + r^{*2}_{long}\right) / \left(2R^2\right)\right]. \quad (1)$$

The fitting is done by minimizing χ^2 between calculated and real correlation function. To stay clear of any effects of the strong interaction in the Ξ^* peak the χ^2 is calculated only from the bins with $k^* \leq 60$ MeV/c.

For most central 0-10% event, the highest available statistics bin, it is feasible to perform separate fits of each of the $\pi-\Xi$ charge combinations. The fit results are presented in Figure 3 by a dashed line in the form of 1-σ contours in the (R, Δr^*) plane.

In the analyzes of non-identical particles it is a standard procedure to first correct the the correlation function for the pair purity and subsequently fit without the use of the λ parameter. Performing the purity correction in our case means to multiply the correlation function by a factor of ~ 3. Even small uncertainty in the purity factor may therefore lead to a systematic error in values extracted from the fit, For this reason we have reintroduced the λ parameter in the fit of the already corrected correlation function in a similar way as it is done $\pi-\pi$ HBT. In this way of fitting the obtained λ will not be a measure of non-purities as in [6], but rather a k^*-independent multiplicator of the purity corrections. The convergence of the fit in the vicinity of $\lambda = 1$ is then indicator of the quality of the performed purity correction.

In Figure 3 are shown by solid line results after introduction of the λ to the fit. In these fits λ converges to values $0.8 \leq \lambda \leq 1.2$ and the extracted radii, in

the Figure 3, show better consistency between different charge combinations. The introduction of λ as an additional parameter hence brought change to the extracted Gaussian radii on the order of $10-20\%$.

The separate fitting of individual $\pi-\Xi$ charge combinations cannot be performed for the remaining two centralities due to low available statistics. For mid-peripheral and peripheral data only simultaneous fit to all charge combinations is feasible. In the Figure 4 is then presented for the first time a centrality dependence of extracted Gaussian radii and relative emission asymmetries from a simultaneous fit to the $\pi-\Xi$ correlation function. The results contain only statistical error of the fits.

5 Conclusions

An update on the $\pi-\Xi$ femtoscopic analyzes in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV as measured by the STAR experiment was presented. Comparison of measured data to the theoretical calculations demonstrates an importance of flow-induced correlations between emission coordinates and momenta in order to qualitatively describe the correlation function in the region dominated by strong interaction.

We have presented a centrality dependence of extracted Gaussian $\pi-\Xi$ radii and relative emission asymmetries from a fit to the Coulomb part of the correlation function. The obtained results show significant centrality dependence with the values of the shift on the order of the size of the system. This observation is in qualitative agreement with scenarios of the evolution of the system that include significant collective flow of multi-strange baryons.

Acknowledgments

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